Full Paper

RECRUITMENT MECHANISM OF THE TROPICAL GLASS EELS GENUS *ANGUILLA* IN THE POSO ESTUARY, CENTRAL SULAWESI ISLAND, INDONESIA

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Abstract

In order to understand recruitment mechanism of the tropical anguillid glass eels in the Poso Estuary, Central Sulawesi Island, Indonesia, a year quantitative sampling field was conducted from May 2008 to April 2009. About 11181 specimens of glass eels were fished using line transects method of two triangular scoop nets through 13 times of new moon and 1761 specimens were preserved for examined in the laboratory. It was found that recruitment of glass eels occurred almost throughout the year of investigation and peak of recruitment occurred in August. *Anguilla celebesensis* and *Anguilla* sp. nov 1 were recruited in dry season, *A. marmorata* recruited in dry and rainy seasons, while *A. interioris*, *A. bicolor pacifica* and *Anguilla* spp. nov 2 recruited only in rainy season. *Anguilla celebesensis* (69.17%) was the most dominant species recruited in the estuary followed by *A. marmorata* (23.54%), *Anguilla* spp nov 1 (4.99%), *Anguilla* spp nov 2 (2.03%), *A. interioris* (0.14%) and *A. bicolor pacifica* (0.04%). The onset of recruitment as well as fluctuation of abundance of the tropical anguillid glass eels into Poso estuary were strongly associated with seasonal and circadian rhythmic as well as tidal and lunar cycles that occurred in the central Indonesian regions.

Keywords: *Anguilla*, inshore migration, recruitment, poso estuary, tropical glass eels

Introduction

The freshwater eels of the genus *Anguilla* Schrank, 1978, are widely distributed in the world. Some eel taxonomist reported the occurrence of 18 species and subspecies of *Anguilla* in the world based on traditional morphological studies (Ege, 1939; Matsui, 1972; Castle & Williamson, 1974) and new taxonomy study using morphological and molecular characters (Watanabe *et al*., 2004; 2005; 2006). At present the number of species increased and become 19 species and subspecies by the finding on the new species in genus namely, *A. luzonensis*, from tropical waters of Philippine (Watanabe *et al*., 2009). In fact, recent progress in the taxonomy studies of genus *Anguilla* as the most basal information for biological study. It reflected how interesting and how mysterious of the unique organism which still need to be investigate in various aspect of their life history including recruitment mechanism and inshore migration of the genus during their early life history of glass eel stage.

Glass eels defined here is a development stage of eel from the end of metamorphosis in the leptocephalus stage to the beginning of pigmentation of the adult like shape (stage VA-VIA; Tesch, 1977). A morphological character of the adult eels has been mainly reported for both taxonomy and ecological study of genus *Anguilla*. However, morphological characteristics that are specific for species and subspecies identification have not yet been well developed for the glass eel stages. First representative studies on the morphological characters of the glass eels of genus *Anguilla* is come from the study conducted by Tabeta *et al*. (1976a). The authors reported a key identification of glass eels and elvers based on the sectional counts of vertebrae.

More than 30 years, no significant study was reported for morphological study of the glass eel stage after study by Tabeta *et al*. (1976a) until Sugeha *et al*. (2001a) starting the study on the species identification of the tropical Anguillid glass eels based on morphological study of length measurement and vertebrae counts. The authors was conducted a series of morphological study for glass eel specimens collected in several estuaries of Indonesian Waters including glass eels from Poigar Estuary (Sugeha *et al*., 2001a), Poso Estuary (Sugeha *et al*., 2001b), Dumoga Estuary (Sugeha *et al*., 2006), and Palu Estuary (Sugeha *et al*., 2008b) of Sulawesi Island. Since Indonesia was recognized as the center for eel distribution and dispersal in the world (Aoyama *et al*., 2001; Sugeha *et al*., 2008a & 2008b), it become interesting to study on their species diversity around Indonesian Waters. However, it is also a great challenge to conduct species identification of anguillid eel species and subspecies in such remote area of

Indonesian waters which promising a high possibility of intra-specific variation in the genus (Aoyama *et al.*, 2000). In order to diminish miss-identification, the author was conducting both morphological and molecular analyses for characterize the tropical glass eels recruited in some others estuaries around Indonesian Waters including representative glass eels from Sumatera, Jawa, Kalimantan, Halmahera, and Papua Island (Sugeha *et al.* 2008a). At present 9 species and subspecies of tropical anguillid has been described to inhabit in the Indonesian Waters (Sugeha *et al.*, 2008a) based on crossing check between morphological and molecular characters, mostly in glass eels stage.

During several years of investigation on the pigmentation development of the tropical glass eels from Indonesian waters, Sugeha *et al.* (2008a) has indicating the appearance of specific pigmentation characters that useful to specifically recognize some tropical eel species during their glass eel stage. In contrast to temperate eel species, the developmental differences in pigmentation in the glass eels of tropical anguillid species are largely not described in detail and just determined according to Bertin (1956) without detail descriptions (Arai *et al.*, 1999a, 1999b & 1999c; Arai *et al.*, 2001; Marui *et al.*, 2001; Sugeha *et al.*, 2001a). Different from previous study that using morphological characters alone for species identification of glass eels collected by catch in the mouth of Poso River (Sugeha *et al.*, 2001b), at present the study was conducting using both morphological and genetic analyses in order to identify the species of tropical anguillid eels from Poso Estuary, including to distinguish the species based on pigmentation characters. Further, we carried out the species composition based on a series of monthly and hourly quantitative sample collection during one year investigation as well as glass eel abundance and its association with environmental conditions including lunar, circadian, and tidal rhythms during inshore migration period.

Recruitment mechanism during inshore migration of glass eels into their growth habitats has been reported in some temperate eels including Atlantic eels (Martin, 1995; Powles & Warlen, 2002), Japanese eels (Matsui, 1972; Tsukamoto, 1990), and Australian and New Zealand eels (Sloane, 1984; Jellyman, 1977 & 1979). However, despite of its highest diversity in the world, study on the species recruitment of tropical glass eels just done in the Phillipine waters (Tabeta *et al.*, 1976b; Arai *et al.*, 1999b), Indonesian Waters (Arai *et al.*, 1999a; 1999b; 1999c; 2001; Setiawan *et al.*, 2001; Sugeha *et al.*, 2001a), and Reunion Island (Robinet *et al.*, 2002). In Indonesian waters the study has only been done for *A. marmorata* (Arai *et al.*, 1999b; Sugeha *et al.*, 2001), *A. celebesensis* (Arai *et al.*, 1999b; Sugeha *et al.*, 2001), *A. bicolor pacifica* (Arai *et al.*, 1999a; Sugeha *et al.*, 2001; 2008a; 2008b) and *A. bicolor bicolor* (Setiawan *et al.*, 2001; Arai *et al.*, 1999b). In order to accumulate much more data and information about recruitment of various species of tropical anguillid glass eels, the study was conducted by a quantitative sampling in Poso Estuary, Central Sulawesi Island, Indonesia. The objective of the study is to understand recruitment mechanism of the tropical glass eels genus *anguilla* in the area, based on morphology analysis.

Method

Sampling

A quantitative sampling field has been conducted in the Poso River estuary, Central Sulawesi Island Island, Indonesia (Fig. 1), during night from 18.00 to 05.00, in 13 times of new moon from May 2008 to April 2009. Glass eels were fished along the beach using two triangular scoop nets that operated in 10x10m line transect located at one side of the estuary following the sampling procedure conducted by Sugeha *et al.* (2001; 2006; 2008a; 2008b). Fished specimens were counted and recorded in the field data sheet. If more than 100 caught, remain specimens were released

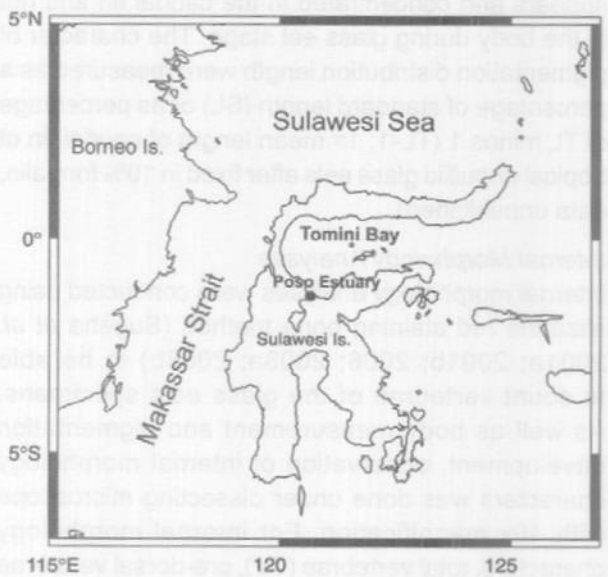

Figure 1. Map that showing sampling location of the tropical glass eels in the Poso Estuary, Central Sulawesi, Indonesia

back to the estuary. The collected specimens were fixed in 10% formalin and transported to the laboratory for future examination. Sample formalin was used for morphological analyses. A portion of sample in each new moon sampling was analyzed using both external and internal morphology analyses.

External Morphology Analyses

External morphology analyses were carried out including body weighing (0.01g), body length measurement of total length (TL), pre-dorsal length (PDL in mm), pre-anal length (PAL), ano-dorsal length (ADL) in mm, also added with measurement of proportion of PDL, PAL, and ADL as percentage of TL. Body length measurements were done according to Tabeta *et al.* (1976a), Tabeta *et al.* (1976b), Tzeng & Tabeta (1983) and Sugeha *et al.* (2001a). After body measurement, pigmentation observation was conducted including pigmentation stage, types and length distribution. Pigmentation stage was adjusted based on Bertin (1956). Pigmentation type was a new character defined in the present study and refers to the earlier position of concentrated pigment melanin in the body (type B), in the body and caudal fin (type BF), and in the caudal fin (type F). Pigmentation length distribution also a new character in the present study and refer to the measurement length of pigment distribution. Pigment length distribution was measured from the body posterior to the body interior trough the lateral line. Therefore, this character could be observed only for pigmentation type B and BF, but not for pigmentation type F were the pigment only appears and concentrated in the caudal fin and not in the body during glass eel stage. The character of pigmentation distribution length were measured as a percentage of standard length (SL) or as percentage of TL minus 1 (TL-1; 1= mean length of caudal fin of tropical anguillid glass eels after fixed in 10% formalin, data unpublished).

Internal Morphology Analyses

Internal morphology analyses were conducted using alizarine red staining bone method (Sugeha *et al.* 2001a; 2001b; 2006; 2008a; 2008b) to be able to count vertebrae of the glass eels specimens. As well as body measurement and pigmentation development, observation of internal morphology characters was done under dissecting microscope with 40x magnification. For internal morphology characters, total vertebrae (TV), pre-dorsal vertebrae (PDV), pre-anal vertebrae (PAV), ano-dorsal vertebrae (ADV), abdominal vertebrae (ABV), caudal vertebrae (CV), and vertebrae beneath operculum or operculum vertebrae (OPV) were counted. Species adjustment using vertebrae count characters was done according to Tabeta *et al.* (1976a), Tabeta *et al.* (1976b), Tzeng & Tabeta (1983) and Sugeha *et al.* (2001a).

Results

External Morphology Characters

A total of 11181 specimens of glass eels were fished from the Poso Estuary, Central Sulawesi Island, Indonesia, from May 2008 to April 2009. About 1761 specimens among them were examined morphologically based on both external and internal characters. Using external characters of body measurements of TL, PDL, PAL ADL and percentage of PDL, PAL and ADL to TL, it was found that all characters were overlapped except for key character of ADL/%TL that could be separated the specimens in two categories (Tabeta *et al.*, 1976a; Sugeha *et al.*, 2001a; Watanabe *et al.*, 2004), termed short-finned eel and long-finned eel. Short-finned eels only represented by one specimen while remain specimens represented the occurrence of long-finned eels. The short-finned eels have ADL about 0% of TL while the long-finned eels have ADL/%TL that ranged from 6.00-19.61 (Table 1). Considering the reported external key character of ADL/%TL (Sugeha *et al.*, 2001) and reported range of distribution of the tropical anguillid eels (Aoyama *et al.*, 2003; Sugeha *et al.*, 2008a), the single short-finned eels were recognized as *A. bicolor pacifica* while the long-finned eels may belongs to *A. celebesensis, A. marmorata*, and *A. interioris*.

Internal Morphology Characters

Further analyses using alizarine red staining bone method was able to count various characters of vertebrae of the tropical anguillid eels including TV, PDV, PAV, ADV, ABV, CV and OPV (Table 2). The key internal characters of ADV was separate the long-finned eels in two categories based on Sugeha *et al.* (2001). First category belong to glass eels with number of ADV ranged from 5-13 and second category belong to glass eels with number of ADV ranged from 14-22. First category identified as characters of *A. celebesensis* (Sugeha *et al.*, 2001) or *A. interioris* (Watanabe *et al.*, 2004) while second category may identified as characters of *A. marmorata* (Sugeha *et al.*, 2001; Watanabe *et al.*, 2004) or *A. interioris* (Watanabe *et al.*, 2004).

Table 1. Character external morphology of the tropical anguillid glass eels collected in the Poso Estuary.

Species	Earlier position of pigmentation	Character	TL (mm)	PDL (mm)	PAL (mm)	ADL (mm)	PDL/%TL	PAL/%TL	ADL/%TL
A. celebesensis	Body	N	809	809	809	809	809	809	809
		Range	45.00~56.00	11.00~16.00	17.00~21.00	3.00~9.00	21.15~31.31	33.64~42.55	6.00~17.65
		Mean	50.29	13.84	19.08	5.24	27.53	37.94	10.41
		SD	1.74	0.77	0.78	0.82	1.38	1.23	1.61
A. marmorata (Type B)	Body	N	533	533	533	533	533	533	533
		Range	45.00~56.00	11.00~15.00	18.00~22.00	5.00~10.00	20.95~29.13	36.00~44.44	10.00~79.61
		Mean	50.77	12.33	20.21	7.88	24.30	39.82	15.52
		SD	1.81	0.56	0.80	0.80	1.08	1.16	1.43
A. marmorata (Type BF)	Body and caudal fin	N	177	177	177	177	177	177	177
		Range	48.00~59.50	11.00~15.00	18.50~22.00	6.00~10.00	20.17~28.57	33.61~43.14	11.43~19.42
		Mean	51.46	12.41	20.44	8.03	24.04	39.59	15.56
		SD	1.78	0.69	0.77	0.78	1.25	1.14	1.44
Anguilla spp. nov 1	Body and caudal fin	N	142	142	142	142	142	142	142
		Range	43.00~55.00	12.00~16.00	17.00~22.00	3.00~8.00	24.00~34.09	34.55~42.55	6.25~16.00
		Mean	48.40	13.99	18.80	4.81	28.98	38.88	9.90
		SD	2.81	0.76	0.92	0.91	2.00	1.35	1.63
Anguilla spp. nov 2	Caudal fin	N	61	61	61	61	61	61	61
		Range	42.00~48.50	12.00~15.00	17.00~20.00	3.00~6.00	27.08~32.97	36.17~43.01	6.38~12.90
		Mean	45.46	13.60	17.75	4.15	29.92	39.05	9.13
		SD	1.51	0.68	0.72	0.70	1.34	1.32	1.54
A. interioris	Caudal fin	N	5	5	5	5	5	5	5
		Range	48.00~54.00	12.00~14.00	20.00~22.00	8.00~9.00	23.53~25.93	36.22~41.67	14.81~17.65
		Mean	51.00	12.60	20.80	8.20	24.69	40.80	16.10
		SD	2.12	0.89	0.84	0.45	1.11	0.94	1.08
A. bicolor pacifica	Caudal fin	N	1	1	1	1	1	1	1
			50.00	18.00	18.00	0.00	36.00	36.00	0.00

Table 2. Character internal morphology of the tropical anguillid glass eels collected in the Poso Estuary.

Species	Earlier position of pigmentation	Character	TV	PDV	PAV	ADV	ABV	CV	OPV
A. celebesensis	Body	N	809	809	809	809	809	809	807
		Range	100~106	20~27	30~40	6~13	33~43	60~70	5
		Mean	102.86	23.22	32.81	9.48	39.47	63.39	5.00
		SD	1.13	1.10	0.93	1.11	0.82	1.22	0.00
A. marmorata (Type B)	Body	N	533	533	533	533	533	533	533
		Range	100~107	18~23	34~39	14~22	39~44	58~65	6
		Mean	103.59	20.30	36.20	15.83	41.45	62.14	6.00
		SD	1.23	0.84	0.77	0.91	0.76	1.20	0.00
A. marmorata (Type BF)	Body and caudal fin	N	177	177	177	177	177	177	177
		Range	100~107	18~23	34~38	14~18	39~44	59~65	6
		Mean	103.46	20.18	36.16	15.92	41.34	62.11	6.00
		SD	1.29	0.86	0.78	0.91	0.90	1.21	0.00
Anguilla spp. nov 1	Body and caudal fin	N	142	142	142	142	142	142	142
		Range	101~107	20~29	31~36	6~13	34~43	60~70	5
		Mean	102.66	24.89	33.77	8.68	39.77	62.89	5.00
		SD	1.22	1.92	1.10	1.41	1.06	1.41	0.00
Anguilla spp. nov 2	Fin	N	61	61	61	61	61	61	61
		Range	100~105	24~29	32~37	5~11	38~42	60~65	5
		Mean	102.02	26.31	34.38	8.07	39.98	62.03	5.00
		SD	1.16	1.22	1.00	1.08	1.06	1.12	0.00
A. interioris	Fin	N	5	5	5	5	5	5	5
		Range	101~106	20~22	36~42	14~17	36~42	60~65	6
		Mean	103.40	21.20	38.00	15.6	40.2	63.20	6.00
		SD	2.30	0.84	2.35	1.14	2.39	1.92	0.00
A. bicolor pacifica	Fin	N	1	1	1	1	1	1	1
			105	36	36	0	42	69	6

Pigmentation Characters

Examination on the pigmentation characters in the present study was divided into pigmentation position, pigmentation type, pigmentation stage, and pigmentation length. Based on observation of pigmentation position (Table 3), it was found that position of pigmentation of short-finned eels located in the caudal fin and belong to pigmentation type F. Position of pigmentation of the long-finned eels were varied in three categories, 1) in the caudal fin, 2) in the body and 3) in the body and caudal fin. The three categories of pigmentation were typically symbolized as F, B and BF, respectively. Glass eels with of the first category have character ADL/%TL that range from 6.38-17.65, the second category from 6.00-19.61, and the third category from 6.25-19.42. It suggested that there was a great overlapped on the key character of external morphology when linked with pigmentation position. It was found that *A. marmorata* may belong to pigmentation type B with position of pigmentation located in the body and pigmentation type BF with position of pigmentation located in the body and caudal fin. This character might be useful clue to separate *A. marmorata* from *A. interioris* with its pigmentation type F that located in the caudal fin. However, if linked with ADV characters, the two pigmentation types of *A. marmorata* were overlap from 14 to 18. It was suggested that pigmentation characters and vertebrae characters of *A. marmorata* species from Poso Estuary was not linked. Looking back to the characters external morphology (Table 1), internal morphology (Table 2), and pigmentation (Table 3), it was found that there are some specimens that have similar character with *A. celebesensis* in both external and internal characters but different in pigmentation characters. Those specimens like *A. celebesensis* have to shown two pigmentation types, some specimens with pigmentation type BF and the other with pigmentation type F (Table 3). In order to critically identify the specimens from Poso Estuary then it was suggested that those specimens which like *A. celebesensis* belong to two new species in the genus *Anguilla*, namely *Anguilla* spp. nov 1 (specimens like *A. celebesensis* with pigmentation type BF) and *Anguilla* spp. nov 2 (specimen like *A. celebesensis* with pigmentation type F).

Species Composition

Based on morphology analysis, it was found that Poso Estuary inhabited by six species of the tropical anguillid eels: *A. celebesensis*, *A. marmorata*, *A. interioris*, *A. bicolor pacifica* and two new species named *Anguilla* spp. nov 1 and *Anguilla* spp. nov 2. Based on total number of specimens collected during monthly sampling from May 2008 to April 2009, it

Table 3. Character pigmentation of the tropical anguillid glass eels collected in the Poso Estuary.

Species	Number of specimen observe	Pigmentation			
		Type	Position	Stage (%)	Distribution length (in % of SL*)
A. celebesensis	809	B	Body	VA (14.09)	23.49
				VB (85.66)	29.55
				VIA (0.24)	31.01
A. marmorata	533	B	Body	VA (83.49)	9.69
				VB (16.14)	5.59
				VIA (0.19)	>50
				VIB (0.19)	>50
	177	BF	Body and fin caudal	VA (40.68)	9.78
				VB (49.15)	11.81
				VIA (7.91)	>50
				VIB (2.26)	>50
Anguilla spp. nov 1	142	BF	Body and fin caudal	VA (46.48)	13.58
				VB (50.70)	26.84
				VIB (2.82)	>50
Anguilla spp. nov 2	61	F	Caudal fin	VA (47.54)	13.73
				VB (47.54)	15.44
				VIA (1.64)	>50
				VIB (3.28)	>50
A. interioris	5	F	Caudal fin	VA (80.00)	10.02
				VB (20.00)	>50
A. bicolor pacifica	1	F	Caudal fin	VB (100)	0

* SL= standard length = (TL-1), where TL is total length and 1 is mean length (mm) of caudal fin

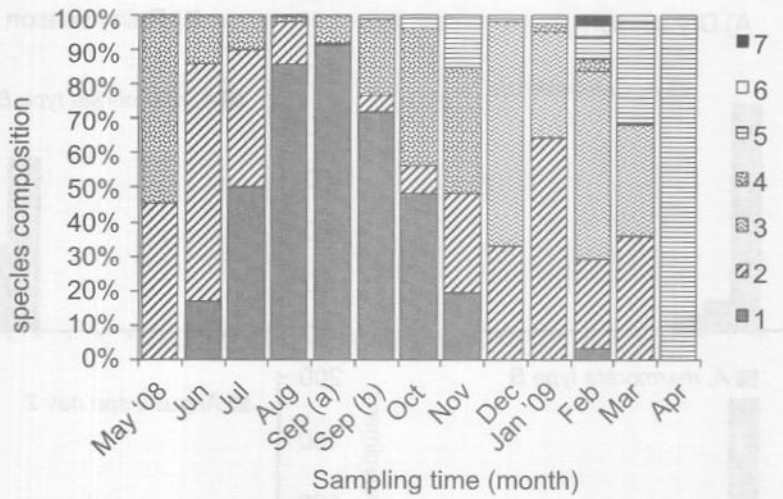

Figure 2. Species composition of the tropical anguillid glass eels recruited in the Poso Estuary, from May 2008 to April 2009. Remarks: ■ : *Anguilla celebesensis* (69.17%); ▨ : *A. marmorata* type B (19.01%); ▨: *A. marmorata* type BF (4.53%); ▨: (*Anguilla* spp. nov 1 (4.99%); ▤: *Anguilla* spp. nov 2 (2.03%); □ : *A. interioris* (0.14%); ■: *A. bicolor pacifica* (0.04%).

was found that *Anguilla celebesensis* (69.17%) was the most dominant species recruited in the estuary and followed by *A. marmorata* (23.54%), *Anguilla* spp. nov 1 (4.99%), *Anguilla* spp. nov 2 (2.03%), *A. interioris* (0.14%) and *A. bicolor pacifica* (0.04%). Species composition of the tropical anguilid glass eels recruited in the Poso Estuary as could be seen in Fig. 2.

Abundance

Based on one year quantitative sampling of glass eels in the Poso Estuary from May 2008 to April 2009, two different seasonal patterns in abundance was detected in associated with two different seasons, dry season (May to September) and rainy season (October to April). Furthermore, species with specific recruitment season which were recruited on that area was also validated. *Anguilla celebesensis*, *A. marmorata* type B and *Anguilla* spp. nov 1 were identified as dry season's species while *A. marmorata* type BF, *Anguilla* spp. nov 2, *A. interioris* and *A. bicolor pacifica* were identified as rainy season's species (Fig. 3). *Anguilla celebesensis* was appeared as dry season's species with relative short period of recruitment from June to September and the peak of abundance was in August. *Anguilla marmorata* type B appeared almost throughout the year, but mostly in dry season with peak of abundance was in August. A relative few recruitment of *A. marmorata* type B was occurred during rainy season with peak of abundance in March. The new species of *Anguilla* spp. nov 1 recruited throughout the year similar with *A. marmorata* type B but with several peaks of abundance in June, August, and September. *Anguilla marmorata* type BF was appeared as rainy season's species with relative short period of recruitment from December to March with peak of abundance in March. A few numbers of new species *Anguilla* spp. nov 2 was founded in late of dry season to rainy season but the peak of abundance was decreased in March. *Anguilla interioris* and *A. bicolor pacifica* was appeared as rainy season's species with peak of abundance in March and February, respectively.

Based on hourly sampling of glass eels in the Poso Estuary in every new moon from May 2008 to April 2009. Two different diurnal patterns in abundance of the tropical anguillid glass eels were observed in association with two different seasons. First diurnal pattern was observed during dry season consisted of *A. celebesensis*, *A. marmorata* type B and *Anguilla* spp. nov 1. Second diurnal pattern was observed during rainy season consisted of *A. marmorata* type BF, *Anguilla* spp. nov 2, *A. interioris* and *A. bicolor pacifica* (Fig. 4).

First pattern showed diurnal recruitment at night (18.00-05.00) with peak of abundance decreased after 02.00. Second pattern also showed diurnal recruitment with two periods of recruitment pattern. The first period occurred at early night (18.00-23.00)

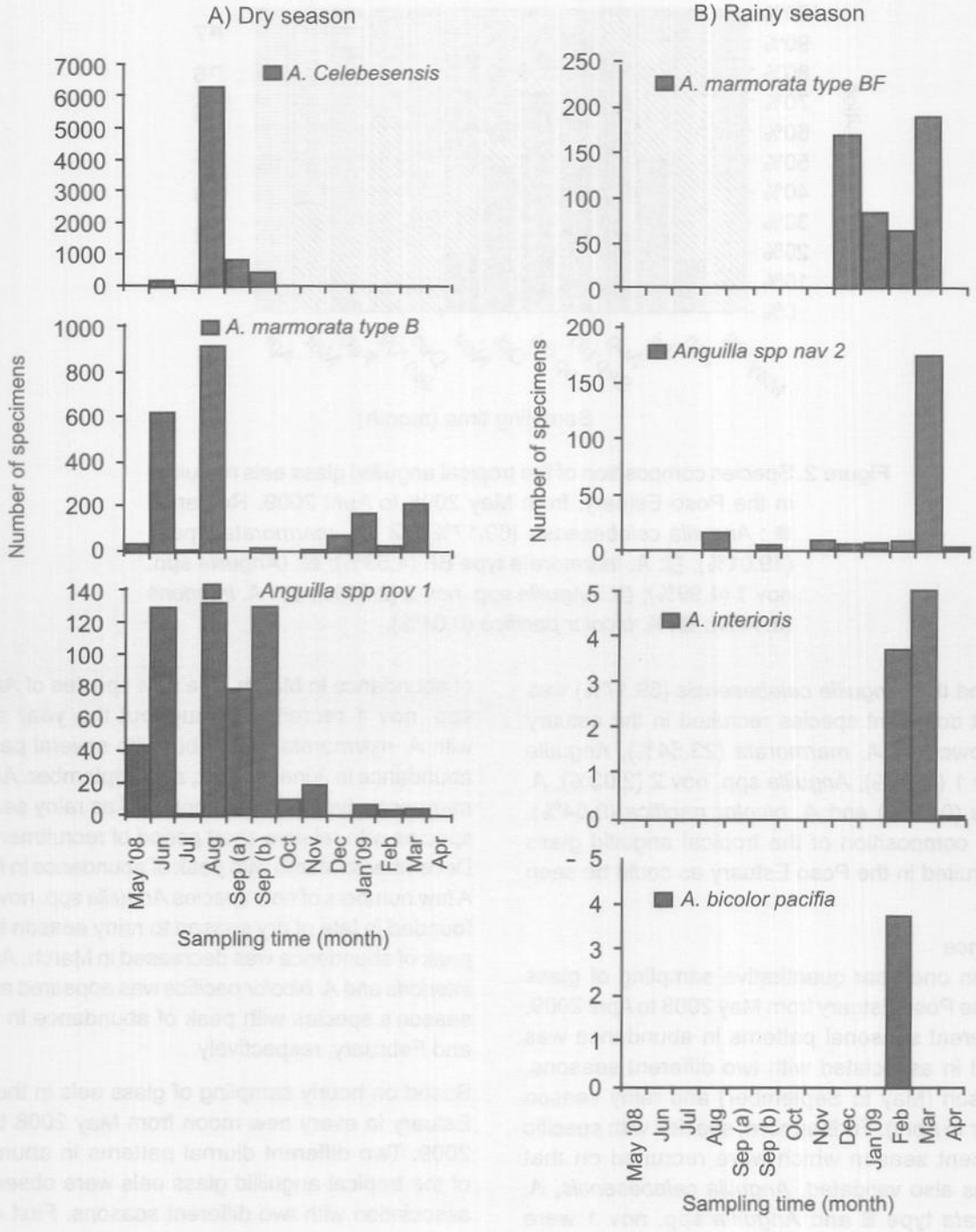

Figure 3. Two different seasonal patterns in abundance of the tropical anguillid glass eels in the Poso Estuary associated with two different seasons in the Indonesian region: A) Dry season and B) Rainy season.

with peak at 22.00 for *A. marmorata* type BF, at 19.00 for *Anguilla* spp. nov 2 and at 20.00 for *A. interioris*. For A. *bicolor pacifica*, only appeared after mid night and did not found during early night. Second period of recruitment occurred at late night (01.00-05.00) with peak at 04.00 for *A. marmorata* type BF, at 03.00 for *Anguilla* spp. nov 2 and only appeared at 04.00 for *A. interioris* and *A. bicolor pacifica*.

Association with Environmental Conditions

The occurrence of various pattern of abundance related to seasonal and diurnal recruitment pattern

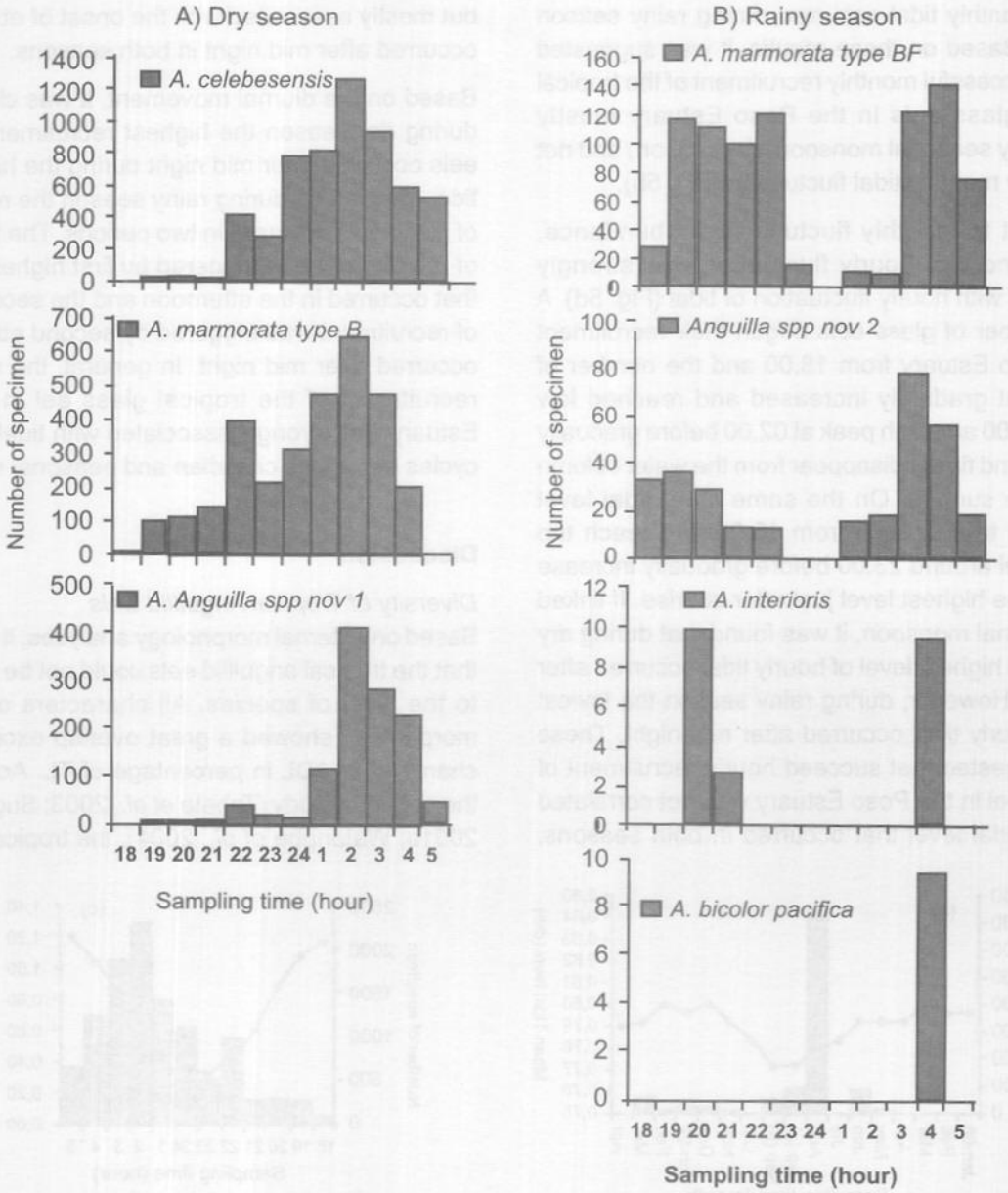

Figure 4. Two different diurnal patterns in abundance of the tropical anguillid glass eels in the Poso Estuary associated with two different season in Indonesian region: A) Dry season and B) Rainy season.

might have association with environmental factor that occurred seasonally and diurnally. To proof this idea then pattern of abundance of glass eels recruited in the Poso Estuary were studied in relation to monthly and hourly tidal rhythmic in Poso area from May 2008 to April 2009 predicted by Indonesian Navy. Based on monthly fluctuation of abundance and its association with monthly fluctuation of tidal, it was found that monthly abundance against monthly tidal. Along the year of investigation the glass eels recruited throughout the year with two clearly period of recruitment. First large recruitment was occurred from May to October with peak in August and second was found to be a small number of recruitment that occurred from November to April with peak in March (Fig. 5a). Interestingly, first period of recruitment was occurred when the fluctuation of monthly tidal was gradually decrease while second period of recruitment was occurred when the fluctuation of monthly tidal was gradually increase. In association with seasonal monsoon, it was found that the lowest level of monthly tidal occurred during dry season while the highest

level of monthly tidal occurred during rainy season (Fig. 5c). Based on these results, it was suggested that the successful monthly recruitment of the tropical anguillid glass eels in the Poso Estuary mostly triggered by seasonal monsoon (dry season) and not affected by monthly tidal fluctuation (Fig. 5b).

In contrast to monthly fluctuation of abundance, it was found that hourly fluctuation was strongly associated with hourly fluctuation of tidal (Fig. 5d). A small number of glass eels began their recruitment in the Poso Estuary from 18.00 and the number of recruitment gradually increased and reached low peak at 22.00 and high peak at 02.00 before gradually decrease and finally disappear from the water column just before sunrise. On the same time, tidal level just began to decrease from 18.00 and reach the lowest level around 23.00 before gradually increase till reach the highest level just after sunrise. If linked with seasonal monsoon, it was found that during dry season the highest level of hourly tidal occurred after mid night. However, during rainy season the lowest level of hourly tidal occurred after mid night. These result suggested that succeed hourly recruitment of the glass eel in the Poso Estuary was not correlated to hourly tidal level that occurred in both seasons, but mostly associated with the onset of ebb tide that occurred after mid night in both seasons.

Based on the diurnal movement, it was cleared that during dry season the highest recruitment of glass eels occurred after mid night during the highest ebb tide. In contrast, during rainy season the recruitment of glass eels occurred in two periods. The first period of recruitment was triggered by first highest ebb tide that occurred in the afternoon and the second period of recruitment was triggered by second ebb tide that occurred after mid night. In general, the successful recruitment of the tropical glass eel in the Poso Estuary was strongly associated with tidal and lunar cycles as well as circadian and seasonal rhythmic.

Discussion

Diversity of Tropical Anguillid Eels

Based on external morphology analyses, it was found that the tropical anguillid eels could not be separated to the level of species. All characters of external morphology showed a great overlap except for the character of ADL in percentage of TL. According to the previous study (Tabeta *et al.*, 2003; Sugeha *et al.*, 2001a; Watanabe *et al.*, 2004), the tropical anguillid

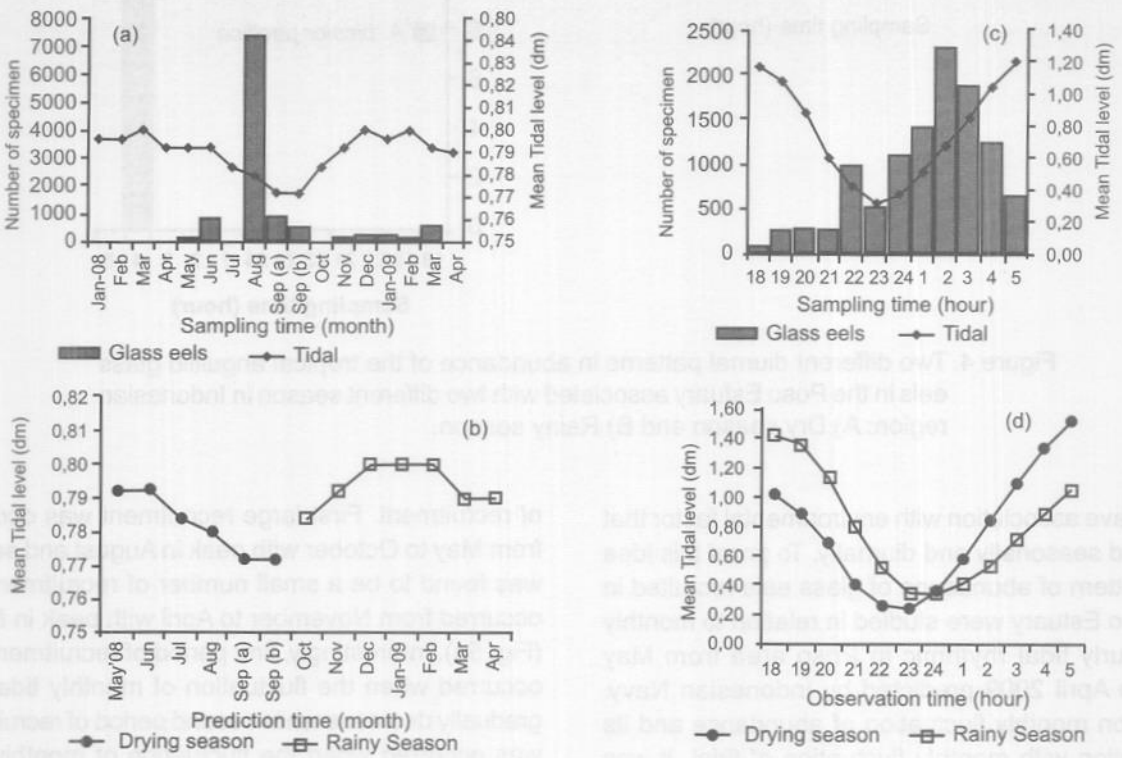

Figure 5. Upper panel: Monthly (a) and hourly (c) abundance of the tropical anguillid glass eels (▬) in the Poso Estuary and its association with tidal rhythmic (—◆—). Lower panel: Contrasting pattern of monthly (b) and hourly (d) tidal rhythmic during drying (—●—) and rainy season (—⊟—).

eel could be separated into two category: short-finned eel and long-finned. The short-finned eels were identified as: *A. bicolor bicolor*, *A. bicolor pacifica* and *A. obscura* while long-finned eels were identified as: *A. nebulosa nebulosa*, *A. celebesensis*, *A. interioris*, *A. borneensis* and *A. marmorata*. However, based on the range of geographic distribution in Indonesian Waters (Ege, 1939; Jespersen, 1940; Watanabe *et al.*, 2004; Aoyama *et al.*, 2003; Sugeha *et al.*, 2008a), only four species that inhabit in the Central Sulawesi Island i.e.: *A. celebesensis*, *A. marmorata*, *A. interioris* and *A. bicolor pacifica*. It means that the short-finned eel recognized in the present study was *A. bicolor pacifica* while the long-finned eels were *A. celebesensis*, *A. interioris* and *A. marmorata*.

Based on morphological characters of ADL/%TL and number of ADV (Table 1), the present study proposed to separate the tropical anguillid eels from Poso Estuary in new category of fin type: 1) short-finned eel, 2) moderate-finned eel, and 3) long-finned eel. Short-finned eel belongs to the tropical eel with average of ADL/%TL = 1 and average of ADV = 1. Moderate-finned eel belongs to the eel with average of ADL/%TL about 9 to 10, and average of ADV about 8-9. Long-finned eel belongs to the eel with average of ADL/%TL and ADV about 15-16 and 15, respectively. Each new species belong to moderate-finned eel with ADL/%TL about 9 in average and ADV about 8 in average, as could be seen in Table 3. Based on those propose ideas, we concluded that Poso Estuary were recruited by one short-finned eels (*A. bicolor pacifica*), three moderate-finned eels (*A. celebesensis*, *Anguilla* spp. nov 1 and *Anguilla* spp. nov 2), and two long-finned eels (*A. marmorata* and *A. interioris*). The pigment that concentrated in the caudal fin was interesting since this character usually only appeared in the short-finned eel (*A. bicolor pacifica*) also appeared in the moderate-finned eel (*Anguilla* spp. nov 2) and long-finned eel (*A. interioris*). It showed that pigmentation position could be used as powerful key characters to identify the three species in the tropical region, especially in Poso Estuary (Table 3). In relating to geographic distribution of the species in the central Indonesian waters, the category of the species as moderate-finned eel species with specific character of pigmentation position that firstly appeared in the body only, then *A. celebesensis* could be separated from the other tropical anguillid eel. *Anguilla interioris* and *A. marmorata* were long-finned eels but *A. celebesensis* could be distinguished from *A. interioris* and *A. marmorata* based on pigmentation position. Early pigmentation position of *A. interioris* were located in the caudal fin (type F) while *A. marmorata* in the body (type B) and body and caudal fin (type BF).

Pigmentation stage and pigmentation length of distribution in the tropical anguillid eels could be analyzed after the species was determined (Table 3). Mostly tropical eel species (*A. celebesensis*, *A. marmorata* type B and BF, *Anguilla* spp. nov 1 and *Anguilla* spp. nov 2) identified in the present study was in advance of pigmentation stage from VA, VB, VIA to VIB, except for *A. interioris* (VA and VB) and *A. bicolor pacifica* (VB). According to Tesch (1977) pigmentation development is strongly association with light intensity and water temperature. It is developed at a time when the eels arrived in the coastal waters until entering estuarine area, abandon their purely pelagic existence. It might be suggested that species with more advance pigmentation stage lived longer in coastal waters condition while species with earlier pigmentation stage was shorter. Related to the water temperature, it might be suggested that the species with more advance pigmentation stages came from tropical waters or belong to tropical eel species while the other species with earlier pigmentation stages came from subtropical waters or belong to subtropical eel species.

According to Aoyama *et al.* (2003) and Kuroki *et al.* (2006), tropical eel species has short-range oceanic migration. Subtropical eel species has mid-range oceanic migration and temperate eel has large-range oceanic migration from spawning ground to recruitment area (Kuroki *et al.*, 2006). Based on Kuroki's study, it could be concluded that *A. celebesensis*, *A. marmorata*, *Anguilla* spp. nov 1 and *Anguilla* spp. nov 2 that identified in the present study belong to tropical eel species that had to experienced short-range oceanic migration while *A. interioris* and *A. bicolor pacifica* belong to subtropical eel species that had mid-range oceanic migration. It might be the reason why the last two species was only recruited in small number of individuals compared to the other species, because migration distance was playing an important role on the successful recruitment of glass eel into their recruitment area.

Tropical Glass Eel Abundance and Its Association with Environmental Condition

In the present study, two different seasonal patterns in abundance of the tropical anguillid glass eels was detected in association with two different seasons in

the Indonesian region, dry season (May to September) and rainy season (October to April). Species specific recruitment season in the Poso Estuary was revealed and termed as dry season's species and rainy season's species. *Anguilla celebesensis*, *A. marmorata* type B and *Anguilla* spp. nov 1 was appear as dry season's species while *A. marmorata* type BF, *Anguilla* spp. nov 2, *A. interioris*, and *A. bicolor pacifica* were appeared as rainy season's species. Sugeha *et al.* (2008a) reported the occurrence of two recruitment patterns in abundance along the Indonesian waters: dry season pattern that occurred in the central Indonesian waters and rainy season pattern that occurred in the west and east Indonesian waters. The present study was recognized that an exceptional recruitment patterns just occurred in the estuary of Poso River, Central Sulawesi Island. Dry season and rainy season pattern of glass eel recruitment was detected on that area. This result was also clarified previous hypothesis about inshore migration mechanism of the tropical glass eels in estuary of Poso River (Sugeha *et al.*, 2001b). It was revised that inshore migration mechanism of the tropical glass eels in the estuary of Poso River was occurred a half year for dry season species and a half year for rainy season species. Furthermore, the authors suggested that those differences in recruitment pattern of abundance might be reflecting the differences on their source of spawning population. Based on study by Sugeha *et al.* (2008a), it is reasonable to conclude that dry season's species from Poso Estuary belong to central Indonesian population while rainy season's species from Poso Estuary belong to east Indonesian population. It means that *Anguilla celebesensis*, *A. marmorata* type B and *Anguilla* spp. nov 1 was came from local spawning area while *A. marmorata* type BF, *Anguilla* spp. nov 2, *A. interioris* and *A. bicolor pacifica* came from regional spawning area. If this idea was true, it could be speculated that dry season's species was spawned in Celebes Sea, Maluku Sea and Tomini Bay that were close to their recruitment area in Poso Estuary. Rainy season's species may spawn far from their recruitment area in Poso Estuary, for example to the west of Papua New Guinea of Western North Pacific where their larvae (Jespersen, 1942) and adult geographic distribution ranged (Ege, 1939; Aoyama *et al.*, 2000) ever reported.

The phenomenon of species specific recruitment season in the Poso Estuary could be reasonable since Tomini Bay of Central Sulawesi Island was characterized as semi-enclosed area that oceanographically propagated by seasonal monsoon and mixing area of local current such as Indonesian through flow and current of eddy (Halmahera Eddy) and regional current such north equatorial current (Tomascik *et al.*, 1997). During dry season from May to September, Central Sulawesi Island mostly affected by regional oceanic and climate conditions that come from southern hemisphere with less moisture was carried by the air and steady wind, therefore a great successful of recruitment of eel from local spawning may occurred in this season. In contrast, during east monsoon from October to April, the winds came from northern hemisphere, carried moist air which falls as rain across the Indonesian archipelago, and may act as current direction for successful migration of western north pacific eel population to the Indonesia archipelago. Eastern Indonesian eel population that may derivate from western north pacific spawning population could be successfully recruited in the Poso Estuary even only in small number of glass eel migrant. The eel has to follow the New Guinea Coastal Undercurrent through Halmahera before finally entering semi enclosed waters of Tomini Bay to reach their recruitment area of Poso Estuary. However, if they have to follow the New Guinea Coastal Undercurrent, it is possible also that they may come from South Pacific population. If this idea was true, maybe that was reasonable why *A. interioris* and *A. bicolor pacifica* from rainy season's species has earlier pigmentation stage, because they may come from the "cold water" of New Guinea Coastal Undercurrent while the other rainy season's species (*A. marmorata* type BF and *Anguilla* spp. nov 2) may come from more "warm water" of north equatorial current through Indonesian Trough flow.

Recruitment Mechanism and Its Implication to Migratory Traits and Spawning Ecology

Monthly tidal mostly affected by seasonal rhythmic while hourly tidal mostly affected by circadian rhythmic. Monthly peak of abundance of glass eels that fall in August of dry season was triggered by monthly peak of tidal that fall in March of rainy season. It means that the larvae of tropical eels may spawned in rainy season when the tidal propagate in the central Indonesian waters was in the highest level. The situation supports the eel larvae to transport to their recruitment area without high energy expenditure. A total of six month period from peak of tidal in March of rainy season to peak of recruitment in August of dry season may be reflecting the period of oceanic migration of leptocephalus and inshore migration

of glass eel to reach their recruitment area. This hypothesis in period of oceanic migration till inshore migration was supporting by the previous report on the early life history study of the tropical glass eels using otolith analyses conducted by Arai *et al.* (1999a, 1999b, 1999c & 2001) and Marui *et al.* (2001). The authors found that the age of recruitment of tropical glass eel when collected at the estuary was range from 152 and 177 days or about 5 to 6 months.

In more detail, tropical anguillid eels had to shown species specific recruitment season related to two different monsoons in the Indonesian region. The dry season's species including *A. celebesensis*, *A. marmorata* type B and *Anguilla* spp. nov 1 from Poso Estuary reached a peak of recruitment mostly in August except for *Anguilla* spp. nov 1 that reached some peak of abundance in June, August and September. Previous study reported that age at recruitment of *A. celebesensis* glass eels from Poso Estuary was about 150 days (Arai *et al.*, 2002a) while *A. marmorata* glass eels from Poso Estuary was about 90 days (Budimawan, 1996) and about 170 days (Arai *et al.*, 2002). If those result linked to present study, it could be suggested that spawning season of dry season's species in the Poso Estuary was fall in the late of rainy season, from February to March. Furthermore, in the present study, the rainy season's species including *A. marmorata* type BF, *Anguilla* spp. nov 2, *A. interioris* and *A. bicolor pacifica* reached the peak of recruitment in February to March. In contrast to dry season's species that predicted to spawn in the late of rainy season, the rainy season's species predicted to spawn in the late of dry season, from August to September.

However, the occurrence of big gap of otolith ageing result between Budimawan's study and Arai's study should be carefully evaluated whether it was because of human error or other factors. If compared to study by Arai *et al.* (2002), the author collected the specimens of *A. marmorata* glass eels in Indonesia from June to July (dry season) and hypothesized that spawning season of the species was December to January (rainy season), respectively. Budimawan (1996) analyzed the otolith of *A. marmorata* glass eels from Poso Estuary that collected in January to February (rainy season) and estimated duration of marine marine larval stage was about 97 to 102 days (about 3 months) or by back calculating hatching date they may spawn around November to December (rainy season). If this idea was accepted, it might be possible that specimens studied by Arai *et al.* (2002) and Budimawan (1996) were came from rainy season's species (*A. marmorata* type BF). Arai's study was conducted in the north Sulawesi Island and mostly connected to the Mindanow current and North equatorial current. Budimawan's study in the Central Sulawesi Island and mostly connected to the Halmahera Eddy and New Guinea Coastal Undercurrent. Therefore it was reasonable to understand why Arai *et al.* (2002) proposed the species spawn in the North Equatorial Current of western Pacific while Budimawan (1996) suggested that the spawning area of the same species could be in Maluku Sea and/or Tomini Bay. Despite to the contradiction of spawning ground of *A. marmorata*, it could be conclude that the two studies concurrent and supporting the present study that rainy season specimens of *A. marmorata* type BF may be came from east Indonesian region or not belong to central Indonesian population. Recent study on the multiple population of *A. marmorata* in world (Minegishi *et al.*, 2008) was reported that *A. marmorata* from Sulawesi belong to North Pacific Population. Unfortunately no information from the authors whether the specimens was collected from dry or rainy season except for the possibility on the multiple populations (North and South Pacific populations) of the species in Ambon Island of Indonesia. Further study on the population structure of the tropical anguillid eels from Poso Estuary would be interesting topic to be realized in the future.

Anguilla bicolor pacifica was reported as a Pacific species since the species have the oldest age compared to the other tropical eel species when recruited (Arai *et al.*, 1999a). It was also become a good reason why the species have only few number of successful recruitment because have to face more complex oceanographic conditions of the great ocean. Oldest age might express the longest oceanic migration during larva stage before recruited in the estuary. In the present study, the short-finned eel was belongs to the rainy season's species together with the two new species and *A. marmorata* type BF. Therefore, it could be hypothesis that similar with *A. bicolor pacifica*, the other three species of rainy season's species may came from Pacific Ocean. In order to support these ideas, in the future it was important to conduct early life history study for the other tropical glass eels found in the present study including the two new species (*Anguilla* spp. nov 1 and *Anguilla* spp. nov 2).

The present study was accommodated some interesting subjects related to biology and ecology of the tropical eel from Central Sulawesi Island including taxonomy, population dynamic, recruitment

mechanism, and its association with environmental condition. After the first report on the biology of silver eel (Sugeha *et al.*, 2001c), downstream migration study of silver eel (Sugeha *et al.*, 2006b), short distance spawning migration of leptocephalus (Aoyama *et al.*, 2003), and early life history of glass eels from Sulawesi Island (Budimawan, 1996; Arai *et al.*, 1999a; 1999b; 1999c; 2002; Sugeha *et al.*, 2001b), the present study on the recruitment mechanism of glass eel from Poso Estuary of Central Sulawesi Island has to contribute better understanding on the biology of the tropical eels from the center of Indonesian Waters. However, the lack of scientific information about growth, movement, and migration pattern of yellow eel inhabit in the Poso River system become an important aspect that need to be investigated in the future.

Conclusion

Recruitment of glass eels in the estuary of Poso River was occurred a half year for dry season species and a half year for rainy season species. The onset of recruitment as well as fluctuation of abundance of the tropical anguillid glass eels into Poso estuary were strongly associated with seasonal and circadian rhythmic as well as tidal and lunar cycles that occurred in the central Indonesian regions.

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